CLAIMS

1. A method for determining incipient mechanical failure of an object, the method comprising:

insonifying the object with ultrasonic energy at a selected fundamental frequency;

acquiring amplitude data from the insonified object at said fundamental frequency and a second harmonic of said fundamental frequency; and

generating a non-linear acoustic image from said amplitude data at said fundamental frequency and said second harmonic frequency.

2. The method of claim 1, wherein said non-linear acoustic image is generated by using a ratio of said amplitude data at said second harmonic frequency and the square of said amplitude data at said fundamental frequency.

3. The method of claim 2, wherein said non-linear acoustic image is a beta image constructed in accordance with the expression:

$$\beta = \left(\frac{8}{ak^2}\right)\left(\frac{A_2}{A_1^2}\right) = \frac{8c^2}{\left(a4\pi^2 f_0^2\right)\left(A_2/A_1^2\right)}$$

wherein A_2 is the amplitude of said second harmonic frequency ($2f_0$), A_1 is the amplitude of the fundamental frequency (f_0), $k = 2\pi f_0/c$, wherein c is the velocity of the acoustic signals in the material of the object, and a is a scanning parameter.

4. The method of claim 1, wherein said acquiring amplitude data is implemented with a broadband transducer having a center frequency at about 1.5 times said fundamental frequency.

5. The method of claim 4, wherein said transducer is also used for said insonifying the object with ultrasonic energy.

6. The method of claim 4, further comprising implementing at least one of a backscatter scan and a surface wave scan.

7. The method of claim 6, wherein said insonifying the object with ultrasonic energy is implemented with an excitation pulse having a pulse length of at least 10λ, wherein λ is the wavelength of the excitation pulse at said fundamental frequency.

8. The method of claim 7, wherein for a backscatter scan, said transducer is focused to a depth within the object of at least about 20λ with respect to an outer surface of the object.

9. The method of claim 6, wherein for a surface scan, said transducer is focused so as to include the Rayleigh wave critical angle of the insonified material.

10. The method of claim 9, wherein for a surface scan, said transducer is also focused so as to isolate a surface wave from a direct reflection wave.

11. A method for determining incipient mechanical failure of an object, the method comprising:

insonifying the object with ultrasonic energy at a selected fundamental frequency using at least one of a backscatter scan and a surface wave scan;

focusing a broadband transducer so as to detect amplitude data from the insonified object at said fundamental frequency and a second harmonic of said fundamental frequency;

digitizing and storing said amplitude data at said fundamental frequency and a second harmonic of said fundamental frequency; and

generating a non-linear acoustic image from said amplitude data at said fundamental frequency and said second harmonic frequency.

12. The method of claim 11, wherein said non-linear acoustic image is determined by using a ratio of said amplitude data at said second harmonic frequency and the square of said amplitude data at said fundamental frequency.

13. The method of claim 12, wherein said non-linear acoustic image is a beta image constructed in accordance with the expression:

$$\beta = \left(\frac{8}{ak^2}\right)\left(\frac{A_2}{A_1^2}\right) = \frac{8c^2}{\left(a4\pi^2 f_0^2\right)\left(A_2/A_1^2\right)}$$

wherein A_2 is the amplitude of said second harmonic frequency ($2f_0$), A_1 is the amplitude of the fundamental frequency (f_0), $k = 2\pi f_0/c$, wherein c is the velocity of the acoustic signals in the material of the object, and a is a scanning parameter.

14. The method of claim 11, wherein said broadband transducer has a center frequency of about 1.5 times said fundamental frequency.

15. The method of claim 14, wherein said transducer is also used for said insonifying the object with ultrasonic energy.

16. The method of claim 11, wherein said insonifying the object with ultrasonic energy is implemented with an excitation pulse having a pulse length of at least 10λ, wherein λ is the wavelength of the excitation pulse at said fundamental frequency.

17. The method of claim 16, wherein for a backscatter scan, said transducer is focused to a depth within the object of at least about 20λ with respect to an outer surface of the object.

18. The method of claim 11, wherein for a surface scan, said transducer is focused so as to include the Rayleigh wave critical angle of the insonified material.

19. The method of claim 18, wherein for a surface scan, said transducer is also focused so as to isolate a surface wave from a direct reflection wave.

20. The method of claim 11, wherein said digitizing and storing said amplitude data at said fundamental frequency and a second harmonic of said fundamental frequency is implemented using a first bandpass filter centered at said fundamental frequency and a second bandpass filter centered at said second harmonic of said fundamental frequency.

21. The method of claim 11, wherein said digitizing and storing said amplitude data at said fundamental frequency and a second harmonic of said fundamental frequency is implemented using waveform-analysis software.

22. A system for determining incipient mechanical failure of an object, comprising:

a broadband transducer for insonifying the object with ultrasonic energy at a selected fundamental frequency through at least one of a backscatter scan and a surface wave scan;

said broadband transducer focused so as to detect amplitude data from the insonified object at said fundamental frequency and a second harmonic of said fundamental frequency;

a pulser receiver for receiving detected signals from said transducer; and

a data acquisition computer for storing said amplitude data at said fundamental frequency and a second harmonic of said fundamental frequency in a digitized format;

wherein said stored amplitude data at said fundamental frequency and said second harmonic frequency is used to generate a non-linear acoustic image.

23. The system of claim 22, wherein said non-linear acoustic image is determined by using a ratio of said amplitude data at said second harmonic frequency and the square of said amplitude data at said fundamental frequency.

24. The system of claim 23, wherein said non-linear acoustic image is a beta image constructed in accordance with the expression:

$$\beta = \left(\frac{8}{ak^2}\right)\left(\frac{A_2}{A_1^2}\right) = \frac{8c^2}{\left(a4\pi^2 f_0^2\right)\left(A_2 / A_1^2\right)}$$

wherein A_2 is the amplitude of said second harmonic frequency ($2f_0$), A_1 is the amplitude of the fundamental frequency (f_0), $k = 2\pi f_0/c$, wherein c is the velocity of the acoustic signals in the material of the object, and a is a scanning parameter.

25. The system of claim 22, wherein said broadband transducer has a center frequency of about 1.5 times said fundamental frequency.

26. The system of claim 22, wherein said transducer emits an excitation pulse having a pulse length of at least 10λ, wherein λ is the wavelength of said excitation pulse at said fundamental frequency.

27. The system of claim 26, wherein for a backscatter scan, said transducer is focused to a depth within the object of at least about 20λ with respect to an outer surface of the object.

28. The system of claim 22, wherein for a surface scan, said transducer is focused so as to include the Rayleigh wave critical angle of the insonified material.

29. The system of claim 28, wherein for a surface scan, said transducer is also focused so as to isolate a surface wave from a direct reflection wave.

30. The system of claim 22, further comprising:

a first bandpass filter for receiving detected signals from said pulser receiver, said first bandpass filter centered at said fundamental frequency; and

a second bandpass filter for receiving detected signals from said pulser receiver, said second bandpass filter centered at said second harmonic of said fundamental frequency;

wherein outputs of said first and said second bandpass filter are converted to said digitized format for storage in said data acquisition computer.

31. The system of claim 22, further comprising waveform-analysis software for receiving detected signals from said pulser receiver said waveform-analysis software further outputting digitized amplitude data at said fundamental frequency and said second harmonic of said fundamental frequency for storage in said data acquisition computer.